CAN LAND-USE PATTERNS SERVE AS A PREDICTOR OF PESTICIDE OCCURRENCE WITHIN AN URBAN LANDSCAPE?

Evelyn H. Hopkins[1] and Daniel J. Hippe[2]

AUTHORS: [1]Geographer, and [2]Hydrologist, U.S. Geological Survey, 3039 Amwiler Road, Suite 130, Peachtree Business Center, Atlanta, Georgia 30360-2824.
REFERENCE: Proceedings of the 1999 Georgia Water Resources Conference, held March 30-31, 1999, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, University of Georgia, Athens, Georgia.

Abstract. The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) has focused on relations between land use and water quality in the Nation's streams. The NAWQA design to assess water-quality conditions is based on monitoring streams located in relatively small watersheds (60–150 square miles) that contain a predominance of a single targeted land use. In some NAWQA study areas, such as the Apalachicola-Chattahoochee-Flint River basin, additional spatial surveys were conducted to evaluate the variability of water-quality conditions within and among watersheds representing each targeted land use. Recently (1996-99), the USGS created a digital land-use and land-cover database for most of the upper Chattahoochee River basin and Metropolitan Atlanta, Georgia. The new land-use data are more detailed and cover a larger area of Metropolitan Atlanta than previously available data. This paper addresses whether land-use patterns obtained from this new digital database may be used to predict pesticide concentrations along a gradient of urban land use.

Preliminary analyses indicate that pesticide concentrations in streams increase as the percentage of the associated watersheds that may be treated with pesticides increases. Three classes of pesticides were investigated: selective preemergent herbicides, insecticides, and nonselective herbicides. The relation between land use and pesticide concentrations is substantially better for selective preemergent herbicides, the most widely used class of pesticides, than for the other classes. Additional explanatory information is needed to improve these relations.

INTRODUCTION

Background

The Apalachicola-Chattahoochee-Flint (ACF) River basin was one of the first 20 study areas selected by the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. The NAWQA Program was designed to evaluate the effects of land use on surface- and ground-water quality conditions across the United States (Gilliom and others, 1995). Most surface-water sampling efforts were directed toward streams having relatively small watersheds (60–150 square miles) that represent one major land use (such as irrigated row-crop agriculture). Although watersheds within the ACF River basin generally have mixed land uses, six streams with a predominant land use were selected for intensive study, (Wangsness, 1997). The land uses are urban, suburban, forest, and three types of agriculture (poultry production, and two row-crop areas in differing geologic settings).

Synoptic studies of streams in watersheds with a range of land-use characteristics were conducted to determine if streams with similar land use and hydrologic characteristics had similar water quality. Within the ACF River basin, streams were sampled in March and May 1994 and analyzed for concentrations of nutrients and pesticides. These synoptic studies have demonstrated similarities of water quality within land-use categories and differences among categories (Hippe and Garrett, 1997; Frick and others, 1998).

Few studies have analyzed changes in water quality along the complex gradients within broad land-use groups. The recent availability of USGS high quality digital land-use data for the 1993-94 period in which these synoptic studies were conducted provides an opportunity to examine relations between synoptic data and gradations of urban land use and land cover.

Purpose and Scope

This paper examines the relation between urban land use and pesticide concentrations in 24 streams sampled by the USGS NAWQA Program in May 1994 (fig. 1, table 1). The streams are in the upper Chattahoochee and Flint River basins and coincide with the new land-use data.

Six of the 24 streams were outside of the Metropolitan Atlanta area, but all 24 watersheds have some urban land uses, such as residential or commercial areas. The land-use data were reclassified to identify areas that may receive pesticide applications. For the initial analysis, pesticides were chosen over other chemical constituents (such as trace elements, nutrients, and PAH's) because their synthetic origin, widespread use, and primarily local transport from application areas may provide greater opportunities to link their occurrence in streams to land use within watersheds. Most other chemical constituents have both natural and synthetic sources, local and long-range transport in the atmosphere, and complex geochemical cycling. Pesticide concentrations were evaluated relative to the percent of sampled watershed having potential application areas as the initial step in understanding water quality along gradients of urban use.

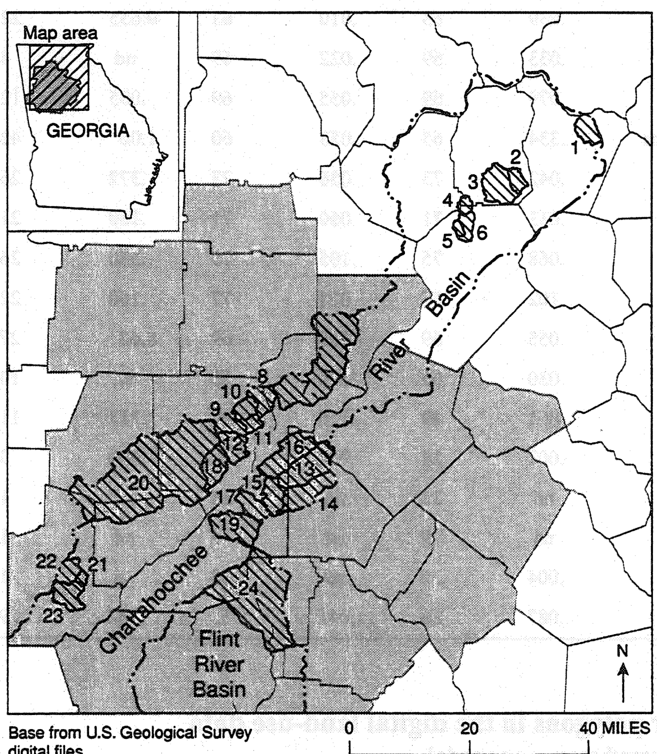

Figure 1. Location of sampled watersheds within the upper Chattahoochee and Flint River basins, 1994.

METHODS

New Digital Land Use Data

Currently, the USGS is producing digital orthophoto quadrangles (DOQs) at 1:24,000 scale for the United States. Aerial photography meeting the standards of the National Aerial Photography Program (NAPP) is the primary data source (U.S. Geological Survey, 1995). As part of the USGS Drinking Water Initiative, the National Mapping Division in Reston, Va., is interpreting these DOQs to create digital land use for the upper Chattahoochee River basin and the Metropolitan Atlanta area. Dates of the original photography are 1993-94 (James D. McNamara, USGS, written commun.,1998).

The format of the DOQ-based data is vector Digital Line Graph-3. Each polygon may have 1 to 5 codes that describe either a land use, a land cover, or a modifier (such as the type of forest or the level of grass management). Examples of these code combinations are shown in table 2.

There are over 140 code combinations in the database. There is no single attribute in the database that summarizes all the codes associated with a polygon. For this paper a new column was created in the database to group the 140 code combinations into 36 codes. These 36 land-use and land-cover code combinations were thought to describe areas as either potential pesticide application areas or areas unlikely to receive pesticide applications. The areas described by the 36 codes were examined by field checking and examination of the DOQs directly. Several code combinations, such as residential-forest and residential-grass, were indistinguishable. Some land-use modifiers had been added by National Mapping Division as the land-use classification project proceeded, such as multi-family residential, airports, and golf courses. Because these modifiers were not applied consistently, the modifiers were not used in the study. On the basis of this examination, the 36 codes were collapsed to 24 codes for land-use and land-cover combinations (table 3).

The DOQ-based land-use dataset has not been completed. The New Georgia quadrangle is the only missing quadrangle affecting this study. It includes the most rural section of the Sweetwater Creek watershed (fig. 1, table 1). For this area only, a composite of older land-use information from the Atlanta Regional Commission and from the Georgia Department of Natural Resources was recoded to match the codes created for the DOQ-based land use (Atlanta Regional Commission, 1995; Georgia Department of Natural Resources, 1995).

Table 1. Sampling sites, pesticide concentrations, and percent of watersheds potentially receiving pesticide applications, upper Chattahoochee and Flint River basins, 1993-94

[mg/L, micrograms per liter; nd, not detected]

Map identification number from figure 1	USGS Site number	USGS site name	Pesticide concentrations and percent of watershed area potentially receiving pesticide applications					
			Selective preemergent herbicides		Insecticides		Nonselective herbicides	
			in µg/L	in percent	in µg/L	in percent	in µg/L	in percent
1	02331247	Deep Creek at Lovett Boyd Woods Road, near Hollywood	nd	7	nd	7	nd	2
2	02331650	White Creek at New Bridge Road, near Cleveland	0.002	7	nd	7	nd	1
3	02331790	Mossy Creek at New Bridge Road, near Cleveland	.006	13	nd	13	nd	1
4	02332810	West Fork Little River at Kenimer Road, near Clermont	.015	11	nd	11	nd	0
5	02332825	Bear Creek at Odum Smallwood Road, near Clermont	nd	6	nd	6	nd	0
6	02332830	West Fork Little River, near Clermont	.009	9	nd	9	nd	0
7	02335760	Big Creek at Riverside Road, near Roswell	.075	32	0.052	32	nd	6
8	02335790	Willeo Creek at State Route 120, near Roswell	.092	62	.111	62	nd	2
9	02335864	Sope Creek at Old Canton Road, near Marietta	.039	63	.010	63	0.635	22
10	02335868	Sewell Mill Creek at Sewell Mill Road, near Marietta	.033	69	.022	69	nd	4
11	02335870	Sope Creek at South Roswell Road, near Marietta	.079	69	.055	69	.035	12
12	02335910	Rottenwood Creek at Interstate North Parkway, near Smyrna	.334	65	.053	60	1.06	42
13	02336130	North Fork Peachtree Creek at Lindber Drive, at Atlanta	.042	73	.056	73	.372	26
14	02336250	South Fork Peachtree Creek at Lenox Road, at Atlanta	.033	71	.060	71	.150	21
15	02336300	Peachtree Creek at Atlanta	.068	75	.105	75	.380	26
16	02336380	Nancy Creek at Randall Mill Road, at Atlanta	.102	77	.028	77	.160	22
17	02336529	Proctor Creek at Northwest Drive, near Atlanta	.055	69	.208	69	8.62	27
18	02336610	Nickajack Creek at Cooper Lake Drive, near Mableton	.030	65	.020	65	nd	10
19	02336728	Utoy Creek at Great Southwest Parkway, near Atlanta	.051	49	.116	49	.217	11
20	02337000	Sweetwater Creek, near Austell	.007	24	.009	23	.300	3
21	02337486	Snake Creek at Horsley Mill Road, near Hulett	nd	36	nd	36	nd	1
22	02337492	Little Snake Creek at Horseley Mill Road, near Hulett	nd	9	nd	9	nd	1
23	02337500	Snake Creek, near Whitesburg	.004	30	nd	30	nd	1
24	02344350	Flint River, near Lovejoy	.087	36	.047	35	.382	19

Table 2. Example code combinations for polygons in the digital land-use data

[code descriptions are in parentheses; —, no code]

First code	Second code	Third code	Fourth code
101 (residential land use)	140 (forest land cover)	606 (deciduous modifier)	607 (evergreen modifier)
102 (commercial/light industrial land use)	130 (grass land cover)	605 (high level management of grass modifier)	—
104 (transportation land use)	178 (manmade land cover)	—	—
105 (communications and utilities land use)	153 (reservoir land cover)	—	—
106 (agricultural land use)	179 (exposed land cover)	611 (confined feeding land use)	—
130 (grass land cover)	141 (scrub/shrub land cover)	604 (medium level management of grass modifier).	—

Table 3. Land-use and land-cover classes and potential pesticide applications, upper Chattahoochee and Flint River basins, 1993-94

[x, land use and land cover that is a potential pesticide application area; —, land use and land cover that is not a potential application area; <, less than]

Description of land-use and land-cover code combinations	Area for 24 watersheds (square miles)	Percent of area for 24 watersheds	Pesticide application code		
			Selective preemergent herbicides	Insecticides	Nonselective herbicides
Residential land use with grass or tree land cover	255	30	x	x	—
Commercial/light industrial land use, grass land cover	20	2	x	x	x
Commercial/light industrial land use, manmade land cover	36	4	x	x	x
Heavy industrial land use, grass land cover	< 1	<1	—	—	—
Heavy industrial land use, manmade land cover	10	1	—	—	x
Transportation land use, grass land cover	2	<1	x	—	x
Transportation land use, manmade land cover	16	2	—	—	x
Recreational land use, grass land cover	8	1	x	x	—
Recreational land use, manmade land cover	< 1	<1	—	—	—
Utilities land use, grass land cover	6	1	—	—	x
Utilities land use, manmade land cover	<1	<1	—	—	x
Institutional land use, grass land cover	6	1	x	x	—
Institutional land use, manmade land cover	3	<1	—	—	x
Cemetery land use, grass land cover	2	<1	x	x	—
Orchard or nursery land use	1	<1	x	x	—
Cropland	1	<1	x	x	—
Agricultural developed land, grass land cover	1	<1	x	—	—
Confined feeding agricultural land use, exposed land cover	3	<1	—	—	—
Tree land cover	356	40	—	—	—
Tree land cover, urban land uses, except residential	1	<1	—	—	—
Grass land cover	95	11	—	—	—
Wetland	5	1	—	—	—
Water	5	1	—	—	—
Other land uses	7	1	—	—	—

Water Quality

In May 1994, water-quality samples were collected at stream sites located throughout the ACF River basin. Water-quality samples were collected by using NAWQA methods (Shelton, 1994), filtered on site, and extracted by using solid-phase cartridges. Samples were analyzed at the USGS National Water-Quality Laboratory, Arvada, Colo., for 84 pesticide residues by using a Gas Chromatography/Mass Spectrometry method (Zaugg and others, 1995) and a High Performance Liquid Chromatography method (Werner and others, 1996). Most pesticide residues analyzed had minimum detection limits ranging from 0.001 to 0.050 micrograms per liter (μg/L).

For this paper, pesticide residues detected in samples from the 24 stream sites (table 1) were grouped into three broad categories—selective preemergent herbicides, insecticides, and nonselective herbicides based on a combination of the current recommendations by cooperative extension agents, reviews of currently held registrations for the compounds, and best professional judgment (Hippe and Garrett, 1997). Concentrations of individual pesticides were summed within each pesticide category to produce three values for each site for comparison to potential pesticide-use areas (table 1). Pesticide residues that were below minimum detection limits were assigned a concentration of zero for analysis and plotted as 0.001 μg/L in figure 2.

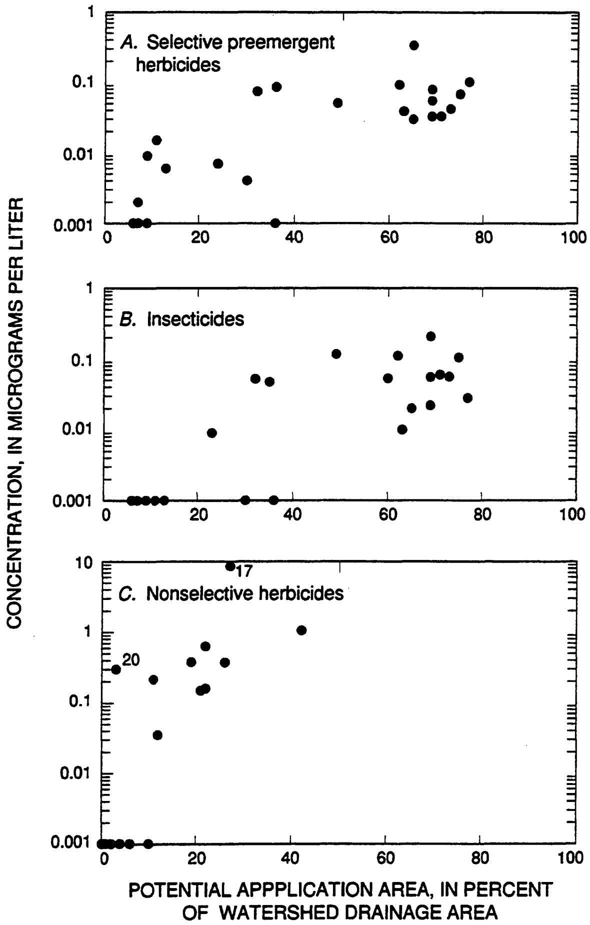

Figure 2. Relations of potential application areas to pesticide concentrations for (*A*) selective preemergent herbicides, (*B*) insecticides, and (*C*) nonselective herbicides, May 1994. (See table 2 for site number and name list.)

Pesticide Application Areas

To examine the relation between pesticide sample concentrations and land use and land cover, the three pesticide groups were assigned to the 24 land-use and land-cover codes (table 3). Selective preemergent herbicides were assigned to land uses where pesticides may be applied to prevent the germination of weeds in turf, such as residential lawns. Insecticides were assigned to the most of the same land uses. Nonselective herbicides were assigned to land uses where pesticides may be applied to control the growth of any vegetation.

Three new land-use datasets were produced with only those polygons with land-use and land-cover combinations that may receive applications of selective preemergent herbicides, insecticides, and nonselective herbicides, respectively. The percentage of potential application area in each watershed was computed for each pesticide group. Actual treated area is much lower than the potential area because most polygons include areas that are not potential treatment areas. For example, areas coded commercial or light industrial land use with grass land cover may include office parks where selective preemergent pesticide applications are applied only to small strips of lawn.

DISCUSSION

Selective Preemergent Herbicides

Selective preemergent herbicides are widely used to prevent or control the germination of broadleaf weeds and annual grasses on turf and crop land. These herbicides are applied primarily in the fall and spring for control of weeds on both cool and warm season turf and in the spring on crops and orchards (University of Georgia, 1999; Landry, 1996).

From 6 to 77 percent of the area of the sampled watersheds may receive selective preemergent herbicides treatments, primarily in residential areas (table 1). Other significant land-use areas include commercial or light industrial, transportation, and recreation (particularly golf courses). No watershed has more than four percent area in agricultural land uses that are likely to receive selective preemergent herbicide applications.

Selective preemergent herbicide concentrations in water-quality samples range from below minimum detection limits to 0.334 μg/L and show a general increase in concentration with increasing percentage of land use receiving applications (fig. 2a). Concentrations typically increase by two orders of magnitude in stream-water samples from watersheds with the lowest to the highest potential application areas.

Insecticides

Insecticides are used to control pest problems on turf, gardens, ornamentals, and crop land, including termites and other wood-infesting insects, fire ants, fleas, mites, grubs, and Japanese beetles. These pesticides are applied throughout the year for structural pest control and during warmer months when insects are most active on turf, gardens, ornamentals, orchards, and cropland (University of Georgia, 1999; Landry, 1996). From 6 to 77 percent of the sampled watersheds are in land uses that may receive treatments with insecticides.

Insecticide concentrations in water-quality samples ranged from below minimum detection limits to 0.208 μg/L and show an overall increase in concentration with increasing percentage of land area that may receive insecticide treatments (fig. 2b). Insecticides were not detected at any watershed having less than 20 percent in potential insecticide application land uses. Insecticides were detected at every stream site where more than 40 percent of the watershed may receive insecticide treatments; however, concentrations within this group vary by about an order of magnitude from 0.010 μg/L to 0.208 μg/L.

Nonselective Herbicides

Nonselective herbicides are used for extended control of most woody or herbaceous vegetation in a variety of settings, including paved areas, utility rights-of-way, power substations, guide rails, fences, and warehouse areas. There is no particular application period for these pesticides; however, many applications may be made during the growing season when there is evidence of regrowth of problem vegetation in previously treated areas (University of Georgia, 1999). From 0 to 42 percent of the land in sampled watersheds are in land uses that may receive treatment with nonselective herbicides, primarily commercial, industrial, and transportation land-use areas.

Nonselective herbicide concentrations in water-quality samples ranged from below minimum detection limits to 8.62 μg/L and show highly variable concentrations in relation to the percentage of land areas that may receive treatments (fig. 2c). The relation of pesticide concentrations to application areas is poorer for nonselective herbicides than for selective preemergent herbicides and insecticides. Nonselective herbicides were detected in every watershed with more than 10 percent potential application areas.

Proctor Creek and Sweetwater Creek are two notable high outliers in the relation between concentrations of nonselective herbicides and landuse (table 1, fig. 1, fig 2). The sum of the concentrations of nonselective herbicides in the Proctor Creek sample was 8.62 μg/L in May, 1994. The Proctor Creek watershed includes a large railroad switching yard and adjoining industrial areas that may have unusually high-use rates and large treated areas. Sweetwater Creek, the largest sampled watershed, has a nonselective herbicide concentration of 0.03 μg/L with only 3 percent of the watershed in land use which might be expected to receive nonselective herbicide treatment. Although Sweetwater's headwaters are in highly developed northeast Cobb County, the southern and western sections of the watershed were largely undeveloped in 1994. It is unlikely that the poor relation was affected by the use of the historic landuse data for this area. An interstate highway and an industrial area are near the Sweetwater Creek sampling site and may have had a disproportionate effect on the sample; however, other watersheds with interstate highways near the sampling site do not show the same high concentration relative to the proportion of potential application areas.

Implications For Predicting Water Quality From Gradients in Land Use

This preliminary analysis suggests that detailed digital land-use and land-cover information may be a useful predictor of pesticide occurrence and concentrations in water samples collected in watersheds with a broad gradient of urban land use and land cover. Some additional procedures may improve these relations:

- supplement the land use and land cover with actual pesticide use statistics (little pesticide-use data are available currently for urban settings);
- normalize the potential application areas to the typical treatment area for a given land use and land cover (for example, recreational areas and large residential lots may have large treatment areas relative to total land area; industrial and commercial areas may have very small treatment areas relative to total land area);
- factor in socioeconomic data to control varied levels of lawn care and grounds maintenance within land use and land cover categories;
- collect additional pesticide occurrence data that better represent the seasons and range of streamflow characteristics.

With the increasing availability of digital orthophotography in the United States, land-use datasets may be created for other urban areas. Further studies may refine the relations between urban land uses and water quality in urban and urbanizing landscapes.

LITERATURE CITED

Atlanta Regional Commission, 1995, *Land Use–Land Cover Digital Database, 1995*: Atlanta, Ga., Atlanta Regional Commission [digital data, *variously paged*].

Frick, E.A and others, 1998, *Water quality of the Apalachicola-Chattahoochee-Flint River basin, Georgia, Alabama, and Florida, 1992-95*: U.S. Geological Survey Circular 1164, 38 p.

Georgia Department of Natural Resources, 1995, *Landcover of Georgia 1988-90*: Georgia Department of Natural Resources, Environmental Protection Division [digital data].

Gilliom, R.J., Alley, W.M., Gurtz, M.E., 1995, *Design of the National Water-Quality Assessment Program: Occurrence and distribution of water-quality conditions*: U.S. Geological Survey Circular 1112, 33 p.

Hippe, D.J., and Garrett, J.W., 1997, *The spatial distribution of dissolved pesticides in surface water of the Apalachicola-Chattahoochee-Flint River basin in relation to land use and pesticide runoff potential ratings, May 1994*, *in* Hatcher, K.J., *ed.*, Proceedings of the 1997 Georgia Water Resources Conference: Athens, Ga., The University of Georgia, Institute of Ecology, p. 410-419.

Landry, Gill, *ed.*, 1996, *Pest control recommendations for professionals*: Athens, Ga., The University of Georgia College of Agricultural and Environmental Sciences, Cooperative Extension Service, 32 p.

Shelton, L.R.,1994, *Field guide for collecting and processing streamwater samples for the National Water-Quality Assessment Program*: U.S. Geological Survey Open-File Report 94-4555, 42 p.

University of Georgia, 1999, *Georgia Pest Control Handbook-1999*, K.S. Delaplane, ed.: Athens, Ga. Georgia Cooperative Extension Service, College of Agriculture and Environmental Sciences, 444 p.

U.S. Geological Survey, 1995, *Digital orthophoto quadrangle data, DeKalb County, Georgia*: U.S. Geological Survey [computer disk].

Wangsness, D.J., 1997, *The National Water-Quality Assessment Program example of study unit design for the Apalachicola-Chattahoochee-Flint River basin in Georgia, Alabama, and Florida, 1991-97*: U.S. Geological Survey Open-File Report 97-48, 29 p.

Werner, S.L., Burkhardt, M.R., and DeRusseau, S.N., 1996, *Methods for analysis by the U.S. Geological survey National Water Quality Laboratory-determination of pesticides in water by Carbopak-B solid-phase extraction and high-performance liquid chromatography*: U.S. Geological Survey Open-File Report 96-216, 42 p.

Zaugg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, *Method of analysis by the U.S. Geological Survey National Water-Quality Laboratory -determination of pesticides in water by C-18 solid-phase extraction and capillary-column gas chromatography/mass spectrometry with selected-ion monitoring*: U.S. Geological Survey Open-File Report 95-181, 49 p.